Ocean Data Assimilation Research at GFDL

Tony Rosati and Brian Gross
NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ

Project Summary

Estimating the state of the Earth System is critical for monitoring our planet's climate and for predicting changes to it on time scales from months to decades. Toward these ends, the vast number of atmospheric observations and the growing number of ocean observations must be combined with model estimates of the state of the Earth System by means of data assimilation systems. This project explores the development of new data assimilation techniques using state-of-the-art ***coupled*** climate models and applies these techniques to detecting climate change, improving forecasts on seasonal to interannual time scales while providing estimates of their uncertainty, and improving our understanding of predictability at decadal time scales in order to provide a foundation for the development of a NOAA capability for decadal forecasts. This capability will provide the Nation's decision and policy makers with the best possible climate information on critical problems such abrupt climate change, changes in hurricane activity, drought, and sea-level rise.

Accomplishments

1. Development of Coupled Data Assimilation System using GFDL's coupled climate model (CM2)

   A fully coupled data assimilation (CDA) system, consisting of an Ensemble Kalman Filter applied to CM2, has been developed to facilitate the detection and prediction of seasonal-to-multidecadal climate variability and climate trends (Zhang et al. 2007). The assimilation provides a self-consistent, temporally continuous estimate of the coupled model state and its uncertainty, in the form of discrete ensemble members, which can be used directly to initialize probabilistic climate forecasts.

2. Climate Detection

   The assimilation system has been evaluated using one CM2.1 simulation of the 20th century as "truth", and assimilating "observations" from that "truth" experiment into a second, independent experiment. "Observations" are taken from the model at places and times where real observations were taken. These observations are then assimilated into a coupled model ensemble that is subjected only to preindustrial forcings. By examining how well this analysis ensemble reproduces the "truth", the skill of the analysis system in recovering anthropogenically forced trends and natural variability is assessed, given the historical observing network. The assimilation is able to successfully reconstruct twentieth-century ocean heat content variability and trends in most locations (Fig.1). The experiments highlight the importance of maintaining key physical relationships among model fields, which are associated with water masses in the ocean and geostrophy in the atmosphere.

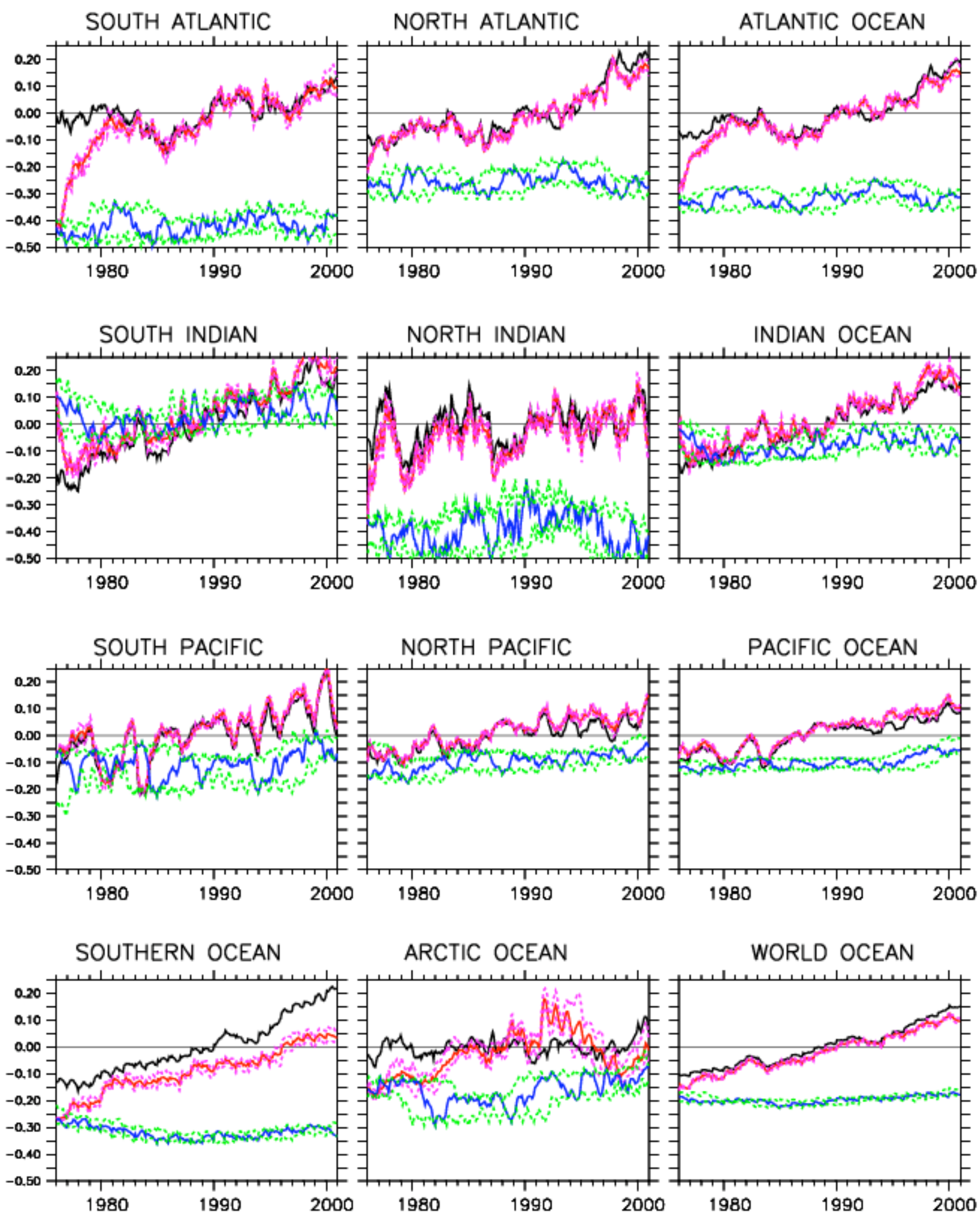

Figure 1 Time series of the anomalies of the top-500m ocean heat content (averaged temperature) in different oceans for the "truth" (black), the ODA (red), and the control (blue). The upper (lower) bounds of the control ODA spread are

plotted by the green-dashed (pink dashed). All anomalies are computed relative to the "truth's" climatology. This figure shows how well the ODA is able to converge to the true solution and capture the simulated warming trend. Sampling issues are noted, in regions that are well observed there is good convergence as in the North Atlantic whereas the southern ocean, where observations are sparse, does not converge to the true solution.

3. Implications for Ocean Observing Systems

The experiments described above indicate that the Atlantic meridional overturning circulation is difficult to constrain using the twentieth-century observational network, but can successfully be reproduced when Argo measurements are available, thereby constraining ocean salinity and density. This preliminary work on assessing the capability of the CDA and ocean observing systems suggests that Argo profiles will be critical for developing a nowcasting capability for the AMOC (Fig.2). Using the CDA system a twenty-five year ocean analysis, for the period 1979-2006, was produced, using XBT, CTD, and Argo observations. The historic ocean state estimation has been extensively analyzed in term of mean and variability (Figs. 3 and 4). This pioneering fully coupled analysis was then used to initialize a set of retrospective seasonal/interannual twelve-month forecasts. It was found that the CDA system showed significantly improved ENSO forecast skill over the previous 3DVar scheme demonstrating the improvement in the initialization scheme.

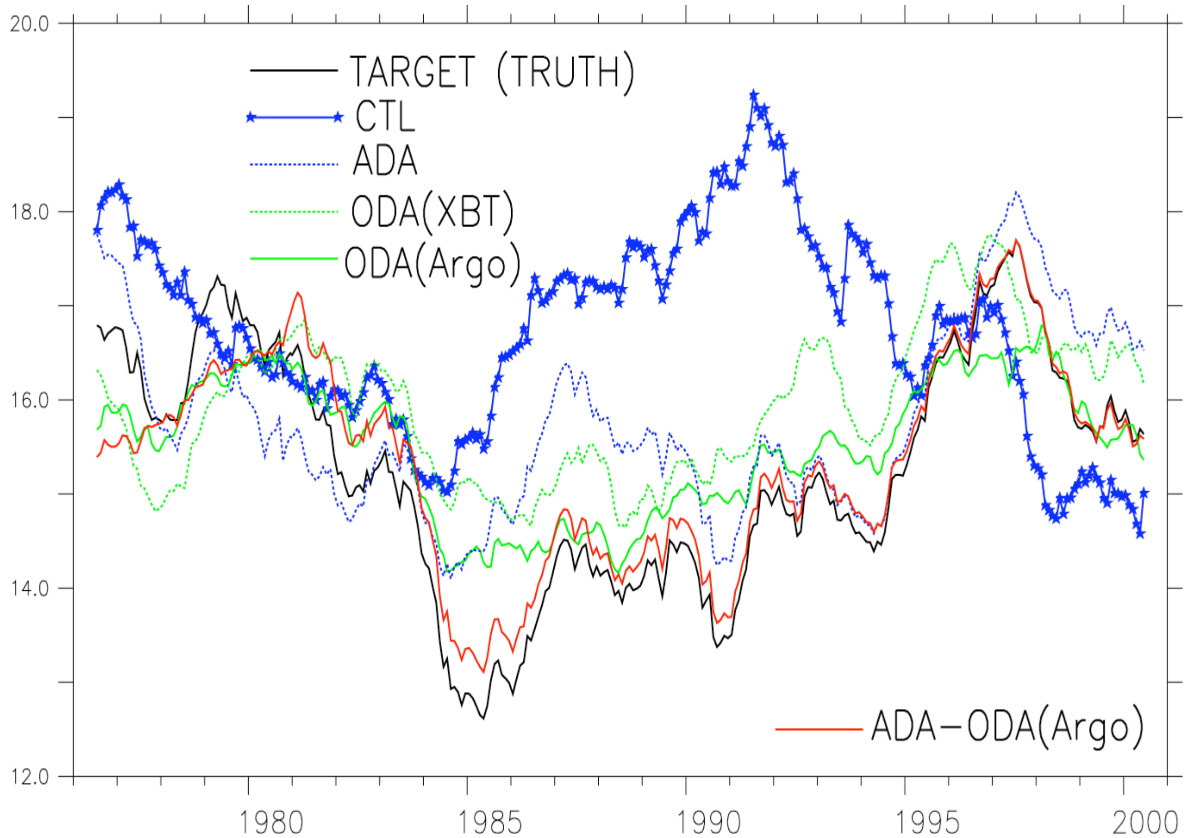

Figure 2 Perfect model studies of the capability of the CDA and observing systems to analyze the AMOC are being carried out at GFDL. The black curve represents a solution from a model simulation. The blue curve represents an independent simulation from which the CDA was initialized. The ADA curve represents only atmospheric data assimilation; the ODA curves represent only ocean data assimilation using the XBT network and the Argo network. The red curve is the coupled ADA and ODA(Argo) and shows the CDA fully recovers the targeted AMOC variability. The y-axis represents AMOC in Sv and x-axis is time in years.

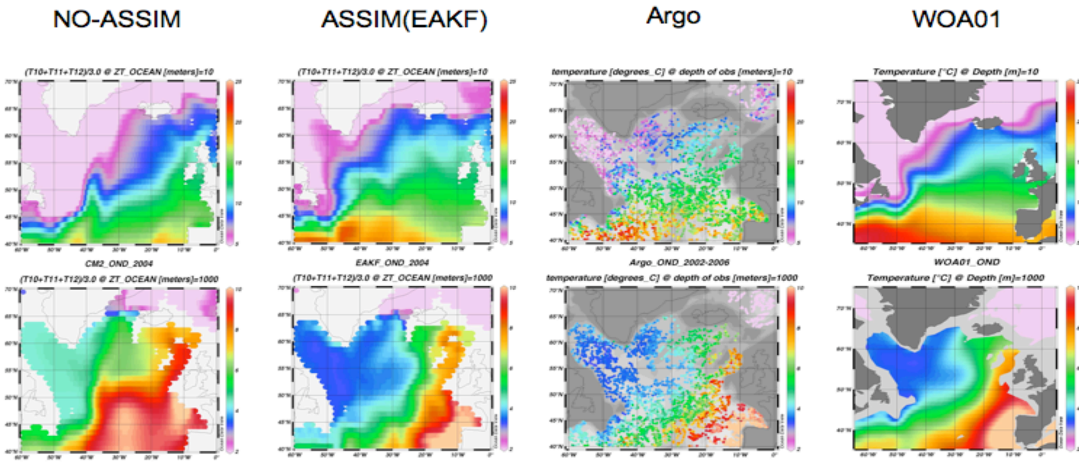

Figure 3 Comparison between ocean model with no data assimilation, with assimilation, just Argo data, and the World Ocean Atlas for OND temperature in the North Atlantic. Top figures are at 10m and bottom are at 1000m. What is shown is that the model without data assimilation has clear bias and that the assimilation case is capturing the data quite well including the variability as may be seen comparing to the WOA.

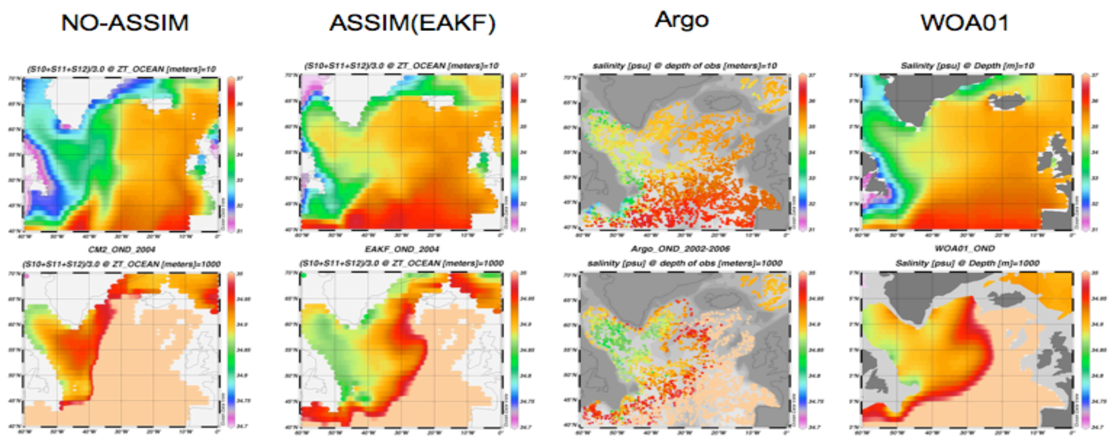

Figure 4 Same as Fig. 3 but for salinity.

4. Development of New Datasets

In order to support the assimilation effort we have had to undertake the task of assembling up to date global temperature and salinity data as well as altimetry data. A Quality Control (QC) system for the Global Temperature-Salinity Profile Program (GTSPP) has been implemented. We identified standard data types from the mixed GTSPP dataset in order to match them with the 20th century ocean assimilation based on the World Ocean Database. However, profiling data from Argo floats, the largest part of GTSPP in the 21st century, should be used with a higher quality delayed mode data. Therefore, another separate QC system investigating an artificial salinity drift is being operated and gradually updated. We now have put together a 25-year historic ocean data set and keep it up to date within one month of real time. In order to undertake the model data comparison, the observed data was optimally interpolated to model positions and times. This three-dimensional gridded dataset will make it easier for statistical analysis regarding the model assessment.

5. Assimilation with Multi-Model Ensembles

Some new and exciting work has begun on a multi-model ensemble assimilation scheme. Both GFDL's CM2.0 and CM2.1 coupled models are used in a unified ensemble system in which the filtering process is based on the error statistics from both models' ensemble integrations. The system construction is complete but the analysis is ongoing. The idea here is that often the ensemble forecasts tend to look more like each other than reality. The goal is that the ensemble spread should span the possible solution space and to include the true solution. Some initial OSSE imperfect twin studies using this system uncovered some inconsistent constraints in the upper and deep ocean due to model biases and the nature of the low frequency of the deep ocean circulation. Although this issue may not be important for seasonal initialization it will most likely be for decadal initialization.

Publications

Zhang, S., M.J. Harrison, A. Rosati, and A. Wittenberg, 2007: System Design and Evaluation of Coupled Ensemble Data Assimilation for Global Oceanic Studies. Mon. Wea. Rev., 135, 3541-3564.

Zhang, S., A. Rosati and M.J. Harrison, 2007: Detection of Multi-Decadal Oceanic Variability within a Coupled Ensemble Data Assimilation System. Accepted JGR Oceans.